SEISMIC HAZARD ZONE REPORT 096

PRELIMINARY REPORT
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October 17, 2004

SEISMIC HAZARD ZONE REPORT FOR THE MORGAN HILL 7.5-MINUTE QUADRANGLE, SANTA CLARA COUNTY, CALIFORNIA

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DEPARTMENT OF CONSERVATION
California Geological Survey

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Morgan Hill 7.5-minute Quadrangle, Santa Clara County, California. The map displays the boundaries of zones of required investigation for liquefaction and earthquake-induced landslides over an area of approximately 62 square miles at a scale of 1 inch = 2,000 feet.

The southeastern end of Santa Clara Valley and parts of the cities of Morgan Hill and San Jose are located within the quadrangle. Northwest-flowing Coyote Creek runs diagonally across the central part of the area and this part of Santa Clara Valley, which separates the Santa Cruz Mountains on the southwest from the Diablo Range on the northeast. At the northwestern corner, Coyote Creek flows toward San Francisco Bay through the Coyote Narrows between the Diablo Range and the Santa Teresa Hills. Within the Diablo Range are several northwest-trending ridges and sub-parallel valleys, one of which contains Anderson Lake, a large reservoir. U. S. Highway 101 (Bayshore Freeway) runs along the northeastern side of Santa Clara Valley and crosses to the center of the valley near the city of Morgan Hill. Little development has occurred along the northern and central part of the valley where much of the land is still used for agriculture. However, significant residential and commercial development has occurred on the valley floor within the city of Morgan Hill.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years.

In the Morgan Hill Quadrangle the liquefaction zone of required investigation covers the Santa Clara Valley floor, the lowlands along Las Animas Creek and San Felipe Creek, and the bottoms of other creek canyons such as Llagas Creek. Approximately 35 percent of the Morgan Hill Quadrangle lies within the earthquake-induced landslide zone of required investigation. Nearly all of the zoned areas fall within the hills and mountains, with virtually none within the Santa Clara Valley.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://gmw.consrv.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Morgan Hill 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Morgan Hill 7.5-Minute Quadrangle, Santa Clara County, California

By
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California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC).

The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Morgan Hill 7.5-Minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking) complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in northern California. During the 1989 Loma Prieta and 1906 San Francisco earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the San Francisco Bay Area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 50 feet of the ground surface. These geological and ground-water conditions are widespread in the San Francisco Bay Area, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard, especially in areas marginal to the bay.

METHODS SUMMARY

The characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill.

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Morgan Hill Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone of required investigation maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Morgan Hill Quadrangle covers an area of approximately 62 square miles in Santa Clara County, including the southeastern end of Santa Clara Valley. Parts of the cities of Morgan Hill and San Jose lie within the quadrangle. The remainder of the area is unincorporated Santa Clara County land. Northwest-flowing Coyote Creek runs diagonally across the quadrangle within this part of Santa Clara Valley, which separates the Santa Cruz Mountains on the southwest from the Diablo Range on the northeast. At the northwestern corner of the quadrangle, Coyote Creek flows toward San Francisco Bay through the Coyote Narrows, between the Diablo Range and the Santa Teresa Hills. A watershed divide exists at the southeastern end of Santa Clara Valley, in the vicinity of Cochran Road in Morgan Hill. This divide separates the Coyote Basin to the north and the Llagas Basin to the south. Elevations within the quadrangle range from about 240 feet to over 2,200 feet. The highest terrain is in the northeastern corner of the quadrangle along Henderson Ridge.

The mountainous Diablo Range in the northeastern half of the quadrangle contains several northwest-trending sub-parallel valleys and intervening ridges. A large reservoir, Anderson Lake, is located within one of these valleys, and Las Animas Creek and San Felipe Creek flow into its northern end. Llagas Creek flows southward within the Santa Cruz Mountains in the southwestern corner of the quadrangle. Llagas Creek is dammed to form Chesbro Reservoir within the Mt. Madonna 7.5-Minute Quadrangle, which lies to the south of the Morgan Hill Quadrangle.

U. S. Highway 101 (Bayshore Freeway) runs along the northeastern side of Santa Clara Valley and crosses to the center of the valley near the city of Morgan Hill. Little development has occurred along the northern and central part of the valley where much of the land is still used for agriculture. However, significant residential and commercial development has occurred on the valley floor within the city of Morgan Hill.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial deposits and artificial fill. To evaluate the areal distribution of Quaternary deposits in the Morgan Hill Quadrangle, bedrock mapping by McLaughlin and others (2001), for the Santa Cruz Mountains, and Wentworth and others (1998), for the Diablo Range, were obtained from the U.S. Geological Survey in digital form and merged with mapping of Quaternary deposits by K.L. Knudsen and R.C. Witter (unpublished). These GIS maps were combined, with minor modifications along the bedrock/Quaternary contact, to form a single, 1:24,000-scale geologic map of the Morgan Hill Quadrangle. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and delineate the liquefaction zones of required investigation.

Other geologic maps and reports reviewed include: Crittenden (1951), State Water Resources Board (1955), California Department of Water Resources (1967), Helley and Brabb (1971), Cooper-Clark and Associates (1974), Rogers and Williams (1974), Helley (1990), Falls (1988), Geomatrix Consultants Inc. (1992), Helley and others (1994), Graymer and DeVito (1993), Iwamura (1995), and Knudsen and others (2000a). Limited field reconnaissance was conducted to confirm the location of geologic contacts, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

Knudsen and Witter (unpublished) identified 20 Quaternary map units in the Morgan Hill Quadrangle, (Plate 1.1). The Quaternary geologic mapping methods used by them are the same as those described by Knudsen and others (2000a), which consist of interpretation of topographic maps, aerial photographs, and soil surveys, as well as compiled published and unpublished geologic maps. They estimate the ages of deposits using: landform shape, relative geomorphic position, cross-cutting relationships, superposition, depth and degree of surface dissection, and relative degree of soil profile development. Table 1.1 compares stratigraphic nomenclature used in Knudsen and others (2000a) and the CGS GIS database, with that of several previous studies performed in northern California.

Quaternary deposits cover about one third of the quadrangle, the majority of which have been deposited by Coyote Creek and its tributaries (Plate 1.1). Much of the sediment in the Coyote Creek system was derived from rocks in the hills to the east of Santa Clara Valley. As described in more detail below, rocks in this area primarily consist of Jurassic and Cretaceous sedimentary and metamorphosed sedimentary rocks, Coast Range Ophiolite, Pliocene Silver Creek Gravel and Plio-Pleistocene Packwood Gravel (Wentworth and others, 1998). These rock units, when eroded, may tend to produce the abundant fine-grained sediment observed in Holocene deposits of the Santa Clara Valley in the Coyote Creek drainage. Coyote Creek flows northwestward and appears confined to the northeastern side of the valley within its natural levee (Qhl) . Along Coyote Creek, Holocene and latest Holocene stream terrace deposits (Qht and Qhty) are inset into Holocene levee and alluvial fan deposits (Qhl and Qhf). Holocene alluvial fan deposits (Qhf) and fine-grained alluvial fan deposits (Qhff) cover the southwestern side of Santa Clara Valley, through which the minor Fischer Creek flows (also northwestward). Several small canyons, such as San Bruno and Springs canyons that open toward the southwestern side of Santa Clara Valley, are mapped as latest Pleistocene to Holocene alluvial fan deposits (Qf). Holocene basin deposits (Qhb) are mapped around the location of a former swampy area known as Laguna Seca at the northwestern end of Santa Clara Valley, at the base of the Santa Teresa Hills. Ground water lost from Coyote Creek farther upstream, discharges to the surface in this area, due to shallow bedrock at the northern end of the valley. A network of artificial channels (ac) drains this area; these channels flow back into Coyote Creek at the northern end of the valley. Latest Pleistocene alluvial fan deposits (Qpf) and latest Pleistocene to Holocene alluvial fan deposits (Qf) underlie much of the city of Morgan Hill. The latest Pleistocene alluvial fan built by Coyote Creek represents a time when the creek may have flowed southwards out to Monterey Bay.

In the southwestern corner of the quadrangle, within the Santa Cruz Mountains, latest Pleistocene to Holocene alluvium (Qa) is mapped along the upland valleys adjacent to the Holocene channel of Llagas Creek (Qhc) and its tributaries. A few latest Holocene stream terrace deposits (Qhty) are inset into the alluvium along Llagas Creek.

In the northeastern corner of the quadrangle, within the Diablo Range, alluvium has been deposited along Las Animas Creek and San Felipe Creek and an unnamed creek in Shingle Valley. All of these creeks flow into Anderson Lake from which flows Coyote Creek. The Holocene channel deposits (Qhc) along both the unnamed creek and Las Animas Creek are inset within undifferentiated latest Pleistocene alluvium (Qpa). The larger San Felipe Creek has deposited undifferentiated Holocene alluvium along the canyon floor (Qha) into which Holocene and latest Holocene stream terrace deposits (Qht and Qhty) are inset. Some stream terrace deposits of latest Pleistocene age and older also have been identified along San Felipe Creek (Qpt, Qot, Qot1, Qot2), west of the Calaveras Fault.

Bedrock exposed in the Morgan Hill Quadrangle consists of Franciscan Complex rocks that are structurally overlain by the Coast Range Ophiolite and Mezozoic marine deposits of the Great Valley Sequence (Wentworth and others, 1998). Wentworth and others (1998) divided this area into several distinct structural blocks, each with a contrasting geologic history. These fault-bounded blocks are generally elongate along a northwest-southeast trend. They include, from the southwest: the New Almaden Block, southwest of the Santa Clara (Coyote Creek) Valley; the Silver Creek Block, on the northeastern side of the valley; the Coyote Block, separated from the Silver Creek Block by the northwest-striking Calaveras Fault; and a small wedge of the Alum Rock Block situated in the north-central portion of the quadrangle.

The New Almaden Block within the Morgan Hill Quadrangle is comprised of mainly Upper Cretaceous Franciscan mélange (fm) whose matrix consists of lithic metasandstone and sheared argillite (McLaughlin and others, 2001). Lesser amounts of Jurassic serpentinized ultramafic rocks (Jos) and Lower Cretaceous volcanic rocks, mostly basalt, flow breccias and andesitic tuff (fpv), also crop out in this area. Other rocks that are found in this block include Lower Jurassic basaltic rocks (fmv), Upper and Lower Cretaceous foramniferal limestone (fpl), Lower Cretaceous and Jurassic chert (fmc), and blocks of chert, amphibolite and basaltic volcanic rocks (fc, am, v). There are also a few outcrops of Miocene (?) silica carbonate deposits (scm), many of which are associated with mercury mineralization in the New Almaden mining district (Wentworth and others, 1998). The Silver Creek Block mainly is comprised of serpentinized Coast Range Ophiolite (Jos), Pliocene Silver Creek Gravel (Tsg) and minor Pliocene basalt (Tba), and Plio-Pleistocene Packwood Gravel (QTp) (Wentworth and others, 1998). The Coyote Block contains faulted blocks of Cretaceous sedimentary rocks (Kcusm), some Franciscan melange basement rocks (fm), and Miocene and Eocene sandstone, siltstone, shale and mudstone (Tbr, Tcc, Tbmw). The Alum Rock Block within the Morgan Hill Quadrangle is comprised of Knoxville Formation (KJk) and intrusive mafic rocks from old ocean crust (Jic) (Wentworth and others, 1998).

See the Earthquake Induced Landslide portion (Section 2) of this report for additional description of bedrock units and geologic structure.

UNIT	Knudsen and others (2000a)	Helley and others (1994)	Helley and others (1979)	Wentworth and others (1998)	CGS GIS database
artificial channel	ac				ac
artificial fill	af			af	af
artificial levee fill	alf				alf
gravel quarries and percolation ponds	gq	PP,GP		PP,GP	gq
modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhc	Qhc
latest Holocene stream terrace deposits	Qhty				Qhty
latest Holocene alluvial deposits, undifferentiated	Qhay				Qhay
Holocene basin deposits	Qhb	Qhb		Qhb	Qhb
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qham, Qhac	Qhf, Qhfp	Qhf
Holocene alluvial fan deposits, fine grained facies	Qhff		Qhaf		Qhff
Holocene alluvial fan levee deposits	Qhl	Qhl		Qh1	Qhl
Holocene stream terrace deposits	Qht	Qhfp		Qht	Qht
Holocene alluvium, undifferentiated	Qha			Qha	Qha
latest Pleistocene to Holocene alluvial fan deposits	Qf				Qf
latest Pleistocene to Holocene alluvium, undifferentiated	Qa			Qa	Qa
latest Pleistocene alluvium, undifferentiated	Qpa	Qpaf	Qpa		Qpa
latest Pleistocene alluvial fan deposits	Qpf	Qpaf		Qpf	Qpf
latest Pleistocene stream terrace deposits	Qpt				Qpt
early to middle Pleistocene alluvial fan deposits	Qof		Qof		Qof?

early to middle Pleistocene stream terrace deposit	Qot, Qot1, Qot2				Qot
early to middle Pleistocene undifferentiated alluvial deposits	Qoa		Qpea, Qpmc	Qoa	Qoa
bedrock	br	Br			br

Table 1.1. Correlation of Quaternary Stratigraphic Nomenclatures Used in Previous Studies. For this study, CGS has adopted the nomenclature of Knudsen and others (2000a).

Structural Geology

The Morgan Hill Quadrangle is within the active San Andreas Fault system, which distributes shearing across a complex system of primarily northwest-trending, right-lateral, strike-slip faults that include the San Andreas, Hayward, and Calaveras faults. The San Andreas Fault is located 9.5 km (6 miles) southwest of the southwestern corner of the Morgan Hill Quadrangle and 16 km or 10 miles southwest of the city of Morgan Hill. The northwest-striking Calaveras Fault passes through the northeastern corner of the map area, about 6 km (4 miles) northeast of the city of Morgan Hill at its closest point (California Division of Mines and Geology, 1982). These two faults contribute the greatest potential ground motions to this area.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical projects. For this investigation 65 borehole logs were collected from files at the city of Morgan Hill, the city of San Jose, the consulting company Pacific Geotechnical, Santa Clara County and Caltrans. Data from 61 borehole logs were entered into a CGS geotechnical GIS database (Table 1.2).

Standard Penetration Tests (SPTs), which are often reported in borehole logs, provide a standardized measure of the penetration resistance of geologic deposits and commonly are used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586) are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

As stated above, geotechnical and environmental borehole logs provide information on lithologic and engineering characteristics of Quaternary deposits. Geotechnical characteristics of the Quaternary map units are summarized in Table 1.2 and their composition by soil type is presented in Table 1.3. These tables reveal that: 1) Holocene materials generally are less dense and more readily penetrated than Pleistocene materials; 2) latest Pleistocene alluvial fan deposits (Qpf) have higher dry density and much higher penetration resistance than Holocene alluvial fan deposits (Qhf), though few measurements were available for the latter; 3) latest Pleistocene alluvial fan deposits (Qpf) contain more gravel and are coarser than Holocene alluvial fan deposits (Qhf); 4) Holocene alluvial fan deposits are predominantly fine grained, but have silt and sand lenses that have the potential to liquefy; and 5) most units have a wide range in their dry density and penetration resistance.

GEOLOGIC MAP UNIT		DRY DENSITY (pounds per cubic foot)						STANDARD PENETRATION RESISTANCE (blows per foot, $(N_1)_{60}$)					
Unit (1)	Texture (2)	Number of Tests	Mean	C (3)	Median	Min	Max	Number of Tests	Mean	C (3)	Median	Min	Max
f	ine	0	-	-	-	-	-	0	-	-	-	.	-
	oarse	3	118.1	.0	118.0	12.	4	4	35	1.3	15	[illegible]	9
Qhty	Fine	0	-	-	-	-	-	0	-	-	-	-	-
	Coarse	0	-	-	-	-	-	1	38	-	-	-	-
Qhl	ine	15	93.0	.1	96.0	67.5	1	12	23	.4	22	[illegible]	41
	oarse	0	-	-	-	-	-	0	-	-	-	.	-
Qhf	Fine	6	96.7	0.08	97.0	86	109.0	6	19	0.48	18	8	36
	Coarse	2	108.5	-	-	-	-	9	25	0.66	22	6	63
Qhl	ine	17	105.6	.0	106.0	99.0	7	18	13	.6	10	[illegible]	34
	oarse	0	-	-	-	-	-	0	-	-	-	.	-
Qf	Fine	16	102.6	0.12	107.3	75.0	119.3	24	26	0.91	20	2	87
	Coarse	9	114.0	0.08	111.0	106.0	135.0	26	34	0.62	29	3	94
Qpf	ine	42	112.3	.0	112.1	85.0	8	60	44	.5	39	[illegible]	9
	oarse	35	115.9	.0	118.0	92.4	0	126	41	.5	37	[illegible]	9

Notes:
(1) See Table 1.3 for names of the units listed here.
(2) Fine soils (silt and clay) contain a greater percentage passing the #200 sieve (< .074 mm); coarse soils (sand and gravel) contain a greater percentage not passing the #200 sieve.
(3) C = coefficient of variation (standard deviation divided by the mean)

Table 1.2. Summary of Geotechnical Characteristics for Quaternary Geological Units in the Morgan Hill 7.5-Minute Quadrangle.

Geologic Unit (1)	Description	Total layer thickness (feet)	Composition by Soil Type (Unified Soil Classification System Symbols)	Depth to ground water (feet) (2) and liquefaction susceptibility category assigned to geologic unit			
				<10	10 to 30	30 to 40	>40
af	Artificial fill (3)	21	SC 67%; GC 17%; Other 16%	VH - L	H - L	M - L	VL
alf	Artificial levee fill	0	-	VH-L	H-L	M-L	VL
ac	Artificial stream channel	0	-	VH	H	M	VL
Qhc	Modern stream channel deposits	0	-	VH	H	M	VL
Qhty	Latest Holocene stream terrace deposits	10	GW 100%	H	H	M	VL
Qhay	Latest Holocene alluvial fan deposits	0	-	H	H	M	VL
Qhb	Holocene basin deposits	65	CH 61%; CL 38%; Other 1%	L	L	L	VL
Qhf	Holocene alluvial fan deposits	99	CL 38%; ML 22%; GW 15%; Other 25%	H	M	L	VL
Qhff	Holocene alluvial fan deposits, fine grained facies	0	-	M	M	L	VL
Qhl	Holocene alluvial fan levee deposits	88	CL 79%; CL-ML 21%	H	M	L	VL
Qht	Holocene stream terrace deposits	0	-	H	H	M	VL
Qha	Holocene alluvium, undifferentiated	0	-	M	M	L	VL
Qf	Latest Pleistocene to Holocene alluvial fan deposits	226	GC 32%; ML 18%; SM 16%; CL 12%; Other 22%	L	L	L	VL
Qa	Latest Pleistocene to Holocene alluvium, undifferentiated	0	-	M	L	L	VL
Qpa	Latest Pleistocene alluvium, undifferentiated	0	-	L	L	VL	VL
Qpf	Latest Pleistocene alluvial fan deposits	1286	CL 23%; GW; 19%; GC 16%; SC 13%; Other 29%	L	L	VL	VL
Qpt	Latest Pleistocene stream terrace deposits	0	-	L	L	VL	VL
Qof	Early to middle Pleistocene alluvial fan deposits	0	-	L	L	VL	V L
Qot	Early to middle Pleistocene stream terrace deposits	0	-	L	L	VL	VL
Qoa	Early to middle Pleistocene alluvium, undifferentiated	0	-	L	L	VL	VL
B	Bedrock	n/a	n/a (4)	VL	VL	VL	VL

Notes: (1) Susceptibility assignments are specific to the materials within the Morgan Hill 7.5-Minute Quadrangle.
(2) Based on the Simplified Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and a small number of borehole analyses for some units.
(3) The liquefaction susceptibility of artificial fill ranges widely, depending largely on the nature of the fill, its age, and whether it was compacted during emplacement.
(4) n/a = not applicable

Table 1.3. Liquefaction Susceptibility for Quaternary Map Units Within theMorgan Hill 7.5-Minute Quadrangle. Units indicate relative susceptibility of deposits to liquefaction as a function of material type and ground-water depth within that deposit. VH = very high, H = high, M = moderate, L = low, and VL = very low to none.

GROUND WATER

Liquefaction hazard may exist in areas where depth to ground water is 50 feet or less (SCEC, 1999). CGS uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water surface within alluviated areas.

Ground-water levels were investigated in the Morgan Hill Quadrangle to evaluate the depth to saturated materials. Saturation reduces the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on ground-water elevation contours in USGS Water Supply Papers (Clark 1917; 1924), ground-water information obtained from the Santa Clara Valley Water District (Reymers and Hemmeter, 2002), and from geotechnical borehole logs acquired from the city of Morgan Hill, Santa Clara County, city of San Jose, Pacific Geotechnical Engineering, and Caltrans. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Ground-water levels are thought to be at or near their historical highs in many parts of the Santa Clara Valley. However, three wells in the Coyote Creek Valley, tracked by the SCVWD (Figure 1), from 1937 to 2001, indicate the highest ground water during 1983 (Reymers and Hemmeter, 2002). Ground water in 2001 appears to be as much as 40 feet deeper than in 1983 for well 09S03E16C001 (Figure 1). The ground water elevations for 2001 were contoured in Reymers and Hemmeter (2002) but are much lower and are based on fewer data points than those reported by Clark (1917) for the year 1916 (based on about 75 measurements). Clark (1917) compiled detailed precipitation and ground-water information specifically for the Morgan Hill area. In comparison, wells from Clark (1917) from the same approximate location as well 09S03E16C001 (Figure 1) indicate ground-water elevations of around 355 feet in 1916; similar to the maximum recorded in 1983. Also, the State Water Resources Board (1955) graphed accumulated runoff departure from mean seasonal runoff, which peaked around 1917, thus ground-water information from 1916 should provide a reasonable estimate of historical high ground water for this area. The water levels from 1916 (Clark, 1917) are similar to those from peak levels between 1937 and 2001. Thus, depth to ground-water contours for the valley were constructed from ground-water elevation contours of Clark (1917) for the majority of the Coyote Creek Valley, and from Clark (1924) for the northern end of the valley.

The contours appear to be fairly consistent with ground-water levels measured by the SCVWD and in the geotechnical boreholes collected for this study.

Clark (1917) notes that the ground water flows mainly northwestward into the Coyote Basin, though a small proportion does flow to the south into the adjacent Llagas Basin. Coyote Creek also loses water to the west towards a small parallel drainage (Fischer Creek) on the southwestern side of the Santa Clara Valley in the Morgan Hill Quadrangle. This ground water surfaces and pools at the northwestern end of the valley due to shallow bedrock across the Coyote Narrows (Clark, 1917). The surfacing ground water is currently diverted back to Coyote Creek along a network of artificial channels. This formerly marshy area was known as Laguna Seca and is shown on older topographic maps of the Santa Clara Valley (for example, Clark, 1917; 1924).

Depths to first-encountered water range from 0 to 80 feet , although most of the valley floor has ground-water levels within 40 feet of the ground surface (Plate 1.2). Ground water is deep (greater than 70 feet below the surface) close to the apex of the latest Pleistocene Coyote Creek fan (Qpf) near Anderson Dam. Ground water is closer to the surface towards the western side of the valley, near the center of the city of Morgan Hill, where it is between 5 and 20 feet below the ground surface. A ground-water divide occurs within this quadrangle separating the Coyote Creek Basin to the north and the Llagas Basin to the south. This divide is almost coincident with the topographic surface divide, which approximately follows Cochran Road, although the divide does move a little with the seasons (Clark, 1917). Regional ground-water contours on Plate 1.2 show estimated historical-high water depths, and locations of ground-water data from both SCVWD ground-water monitoring wells and from geotechnical borehole logs from investigations between 1968 and the 2000.

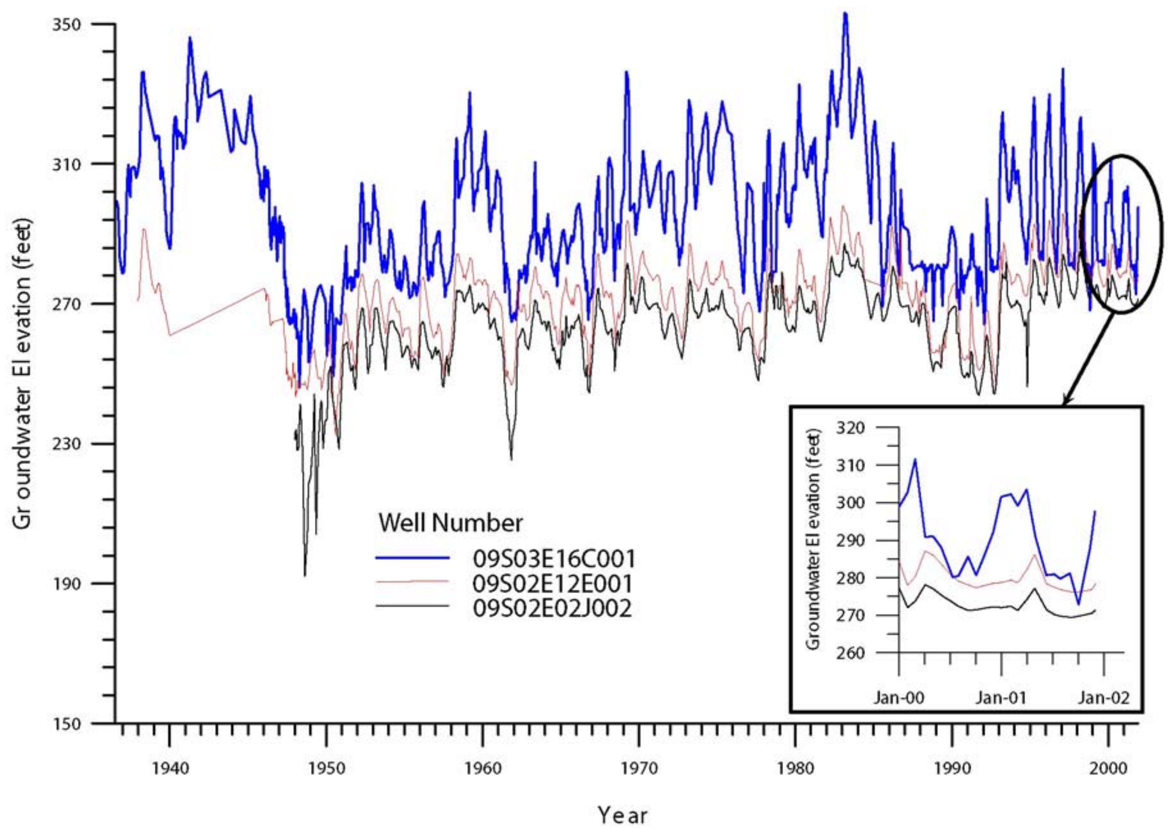

Figure 1.1. Hydrograph for Coyote Creek Valley sub-basin index wells (modified from Figure 3-5 in Reymers and Hemmeter, 2002). One of the three wells is located close to the ground water divide at the southern end of the Coyote Creek Valley (09S03E16C001) and the other two are in the south-central part of the Coyote Creek Valley (09S02E12E001 and 09S02E02J002). Note that fluctuations in annual seasonal ground-water elevation can be as much as about 50 feet for well 09S03E16C001 and less for the other two wells.

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. CGS's qualitative relations among susceptibility, geologic map unit and depth to ground water are summarized in Table 1.3.

Most Holocene materials where water levels are within 30 feet of the ground surface have susceptibility assignments of high (H) to very high (VH) (Table 1.3). Holocene alluvial fan fine facies deposits (Qhff) and undifferentiated Holocene alluvium (Qha) primarily are composed of fine-grained material and have correspondingly lower susceptibility assignments. However, these units may contain lenses of material with higher liquefaction susceptibility. Holocene basin deposits (Qhb) primarily are composed of fine-grained material (Table 1.3) and so are assigned a low (L) liquefaction susceptibility where water levels are within 30 feet of the ground surface. All late Pleistocene and older deposits within 30 feet of the ground surface have low (L) susceptibility except late Pleistocene to Holocene undifferentiated alluvium (Qa). Late Pleistocene to Holocene alluvial fan deposits (Qf) were assigned a low susceptibility in the Morgan Hill Quadrangle because these deposits were found to be similar to those of Pleistocene deposits, with generally higher density and penetration resistance (Table 1.3). Uncompacted artificial fill and latest Holocene alluvial fan levee and stream terrace deposits have moderate (M) susceptibility assignments where they are saturated between 30 and 40 feet. All other units have been assigned low (L) to (VL) susceptibility assignments below 30 feet of the ground surface.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Morgan Hill Quadrangle, PGAs of 0.55-0.64 g, resulting from earthquakes of magnitude 6.2 to 7.9, were used for the liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996). See the ground motion portion (Section 3) of this report for additional description of potential ground motions.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997; Youd and others, 2001). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading to a M7.5 event. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site-specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 61 geotechnical borehole logs reviewed in this study (Plate 1.2), 56 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Morgan Hill Quadrangle is summarized below.

Areas of Past Liquefaction

Knudsen and others (2000a) compiled data from Tinsley and others (1998) and Youd and Hoose (1978) for earthquakes in the San Francisco Bay region. Tinsley and others (1998) compiled observations of evidence for liquefaction for the 1989 Loma Prieta earthquake. Youd and Hoose (1978) compiled them for earlier earthquakes, including 1868 Hayward and 1906 San Francisco earthquakes. The Knudsen and others (2000a) digital database differs from earlier compilation efforts in that the observations were located on a 1:24,000-scale base map versus the smaller- scale base maps used in the earlier publications. Sites were reevaluated and some single sites were broken into two or more where the greater base-map scale allowed.

In the Morgan Hill Quadrangle there is only one area where historical ground failure has been documented. Youd and Hoose (1978) cite a report that cracks from 2-6 inches wide formed in the coarse bottom of the Coyote River near the Fisher Ranch during the 1906 earthquake (site 159 on Plate 1.2). There also was evidence that water had been ejected from those cracks as clean fine material was observed surrounding the cracks. Muddy water was reported to have emanated from the cracks at the time of the 1906 earthquake (Youd and Hoose, 1978).

Artificial Fills

In the Morgan Hill Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for dams and levees. Since these fills are likely to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss simplified procedure. In Holocene alluvial deposits that cover much of flatlands, most of the borehole logs that were analyzed using the Seed-Idriss simplified procedure contain sediment layers that may liquefy under the expected earthquake loading. These areas containing saturated potentially liquefiable material are included in the zone of required investigation.

There is sufficient geotechnical data for the southern part of Santa Clara (Coyote Creek) Valley that includes parts of the city of Morgan Hill. This area is underlain by latest Pleistocene alluvial fan deposits (Qpf), which are dense and have high blow counts (Plate 1.1; Table 1.2). Despite the shallow ground water, especially on the western side of Morgan Hill, the latest Pleistocene alluvial fan deposits are not included in the zone of required investigation due to their age and density. The latest Pleistocene to Holocene alluvial fan deposits (Qf) mapped to the west of the latest Pleistocene alluvial fan (Plate 1.1) also are excluded from the zone of required investigation because of their density, despite the shallow ground water in this area (5-20 feet; Plate 1.2).

Geotechnical information from boreholes near Coyote Creek in the northern part of the quadrangle indicates potential for liquefaction during a major earthquake and so this area is included in the zone of required investigation. Historical liquefaction was observed close to these boreholes during the 1906 earthquake (site 159 of Youd and Hoose, 1978). The area underlain by Holocene basin deposits (Qhb) is saturated to within a few feet of the surface and was historically a marshy area called Laguna Seca. Despite these deposits having low densities and penetration resistance, they are predominantly fine-grained clay and silty clay to a depth of about 20 feet. Therefore, these deposits would not be susceptible to liquefaction. Below the clay deposits are very dense gravelly deposits, interpreted as late Pleistocene in age. This part of the valley has an almost imperceptible gradient and so the risk of lateral spread in these deposits is very unlikely. There are no source areas directly surrounding the small basin that would indicate an influx of sand or silt and no layers of liquefiable material were described in any of the geotechnical boreholes. Thus, these areas underlain by Holocene basin deposits are not included in the zone of required investigation.

Areas with Insufficient Existing Geotechnical Data

Sufficient geotechnical data were not available for a large part of Santa Clara Valley, north of the city of Morgan Hill and south of Bailey Road (Plate 1.2). However, the few shallow boreholes at the head of Coyote Creek near the outlet from Anderson Reservoir indicate that loose silty sand and silt, both of which could potentially liquefy if saturated, occur in the subsurface near Coyote Creek. The Holocene alluvial fan deposits (Qhf, Qhff, Qhl, Qhc, Qhty), where depth to ground water is less than 40 feet, are therefore included within the zone of required investigation. These areas include the majority of Santa Clara Valley that is susceptible to flooding from Coyote Creek for the 100-year flood, and part of which has been inundated historically (Cooper-Clark and Associates, 1974). Geotechnical boreholes close to Coyote Creek, toward the northern end of the valley, penetrate Holocene natural levee, stream terrace and alluvial fan deposits. These boreholes contain layers that were found to be susceptible to liquefaction according to the Seed-Idriss simplified procedure. Latest Pleistocene and Holocene alluvial fan deposits (Qf) mapped along the edges of Santa Clara Valley north of the city of Morgan Hill were not included in the zone of required investigation, because of greater depth to ground water and the fine-grained nature of the deposits observed in the field. Two boreholes that penetrated this unit were interpreted to have thin Holocene deposits over predominantly very stiff to hard latest Pleistocene clay-rich deposits.

All Holocene and latest Holocene channels, undifferentiated alluvium and stream terraces (Qhc, Qha, Qht, Qhty) within the hilly regions to the northeast of Santa Clara Valley are included within the zone of required investigation due to probable shallow ground water and potential for loose silt and sand deposits. The valleys to the southwest of Santa Clara Valley, mapped mostly as undifferentiated latest Pleistocene to Holocene alluvium (Qa) also were included within the zone of required investigation, due to shallow ground water and abundance of silty, sandy and gravelly deposits, as observed in the field.

COMPARISON WITH OTHER LIQUEFACTION STUDIES

In this section, the results obtained during the present study are compared with results from several previous regional liquefaction studies that include the Morgan Hill Quadrangle. Many of the differences between the liquefaction zones in this study and liquefaction susceptibility and potential maps of previous studies result from differences in geologic mapping and the scale of mapping. More important, however, is that most earlier studies were broader and more regional in nature. Investigators did not have access to or utilize as many geotechnical borehole logs as the present study.

Rogers and Williams (1974) mapped liquefaction potential as part of a special report on potential seismic hazards for Santa Clara County. Based on only 7 boreholes, Quaternary geologic mapping and 31 depth-to-ground-water measurements (taken at different times of the year), they mapped liquefaction hazard zones of varying severity within the Morgan Hill Quadrangle. Rogers and Williams (1974) used Quaternary map units from 1:24,000-scale geologic mapping of Helley and Brabb (1971). The major differences between their map and this study are in the areas of Holocene basin deposits at the northern end of the Santa Clara Valley in the Morgan Hill Quadrangle (mapped as Quaternary fluvial and interfluvial basin deposits by Helley and Brabb), which Rogers and Williams (1974) mapped as having a high potential for liquefaction. Rogers and Williams (1974) also mapped a sub-zone of peat deposits thicker than 5 feet in the general location of Laguna Seca as having high potential for liquefaction and differential settlement. They designated most of Santa Clara Valley within the Morgan Hill Quadrangle as an area of moderate potential for liquefaction, lurching and lateral spreading where the water table is 20-50 feet, except for two areas mapped as having low liquefaction potential (Rogers and Williams, 1974). The majority of Santa Clara Valley is included within the liquefaction zone of required investigation in this study, including the two areas designated by Rogers and Williams (1974) as low liquefaction potential. One of these areas of low liquefaction potential is close to Coyote Creek and the location of observed historical liquefaction, and the other is within an area mapped as Holocene alluvial fan and levee deposits (Qhf and Qhl) by Knudsen and Witter (unpublished). Helley and Brabb (1971) mapped the latter area as older alluvial fan deposits.

Cooper-Clark and Associates (1974) evaluated liquefaction potential for the Santa Clara Valley (Coyote Creek portion) as part of a geotechnical investigation for the city of San Jose sphere of influence. Most of the valley is mapped as having high liquefaction potential, with moderately high potential for lateral ground failure. A narrow strip along Coyote Creek and some upland valleys have been mapped as having a high liquefaction potential. The Cooper-Clark and Associates (1974) map does not extend into the city of Morgan Hill and so this part of the quadrangle cannot be compared. The majority of the areas defined by Cooper-Clark and Associates (1974) as having high liquefaction potential are included within the zones of required investigation as defined in this study. However, the upland valley areas along the edges of the Santa Clara Valley and the Holocene basin deposits in the northern part of the quadrangle were not included in the zone of required investigation in this study because geotechnical data indicates that these deposits have low potential for liquefaction.

Geomatrix Consultants Inc. (1992) evaluated liquefaction potential for part of the Morgan Hill Quadrangle in their evaluation for the city of San Jose. For their regional map, they sub-divided areas based on ground-water levels into three distinct sub-areas with depths to ground water of 0 to 10 feet, 10 to 30 feet and greater than 30 feet. Their designation of liquefaction susceptibility is based on the ground-water depth ranges and geologic map units as mapped by Helley and Brabb (1971), Helley and others (1979) and more recent mapping. The mapping they did for this project has, in part, been published as Helley and others (1994). Geomatrix Consultants Inc. (1992) defined ground-water depths to be less than 30 feet for Coyote Creek Valley based on Santa Clara Valley Water District annual reports, as they had no geotechnical boreholes for this area. They assigned areas mapped as Holocene fluvial deposits (Qhf) as variable or unknown liquefaction potential, which includes areas where ground-water conditions are unknown or active stream courses where liquefaction susceptibility is typically high. The areas mapped as Qhf in Geomatrix Consultants Inc. (1992) are included within the zone of required investigation except the area mapped in this study as Holocene basin deposits at Laguna Seca. Geomatrix Consultants Inc. (1992) mapped Pleistocene alluvial fan deposits (Qpa) in upland valley areas on both sides of the Santa Clara Valley as having low liquefaction potential. These upland tributary valleys are excluded from the liquefaction zone of required investigation. Geomatrix Consultants Inc. (1992) mapped an area along the center of the valley, also mapped in their study as Pleistocene alluvial fan deposits, as having low liquefaction potential. This area is included within the zone of required investigation in this study because Knudsen and Witter (unpublished) mapped it as Holocene alluvial fan deposits (Qhf).

Knudsen and others (2000a) recently published new mapping of Quaternary deposits and liquefaction susceptibility for the nine-county San Francisco Bay Region. The Knudsen and others (2000a) liquefaction susceptibility assignments are based on age and type of geologic deposit and ground-water levels. The susceptibility assignment for each geologic map unit was calibrated with occurrence of historical liquefaction, limited borehole log data with penetration tests, and some liquefaction analyses of borehole data. The majority of alluviated areas within the Morgan Hill Quadrangle (except areas mapped as Pleistocene deposits) are designated as having low to moderate liquefaction susceptibility, with only the Holocene stream terrace deposits and channels being designated as having high liquefaction susceptibility. Areas mapped as fine-grained deposits (Qhff and Qhb) were designated as having moderate susceptibility by Knudsen and others (2000a). However, this assignment was based on the correlation of units with actual occurrences of liquefaction and assumed ground-water levels. About 4 percent of the pre-Loma Prieta liquefaction occurrences were observed in this type of fine-grained deposit (Knudsen and others, 2000b).

In comparison to the regional studies described above, CGS's evaluation is based on new mapping of the Quaternary deposits by Knudsen and Witter (unpublished) and geotechnical data specific to the Morgan Hill Quadrangle. The geologic map units have been characterized for this quadrangle based on data collected from 61 geotechnical boreholes that penetrate many of the geologic deposits mapped in the quadrangle. Historical high ground-water contours constructed for this study are more detailed than those used in any previous study and were based on a U.S. Geological Survey Water Supply Paper specific to this area (Clark, 1917). This Water Supply Paper included about 75 ground-water observation wells for the Morgan Hill Quadrangle as shown on Plate VII in Clark (1917).

ACKNOWLEDGMENTS

The author would like to thank Mike Shamamoto and Roger Storz with the city of San Jose; Roger Pierno with the Santa Clara Valley Water District; Jim Baker, County Geologist with the Santa Clara County; David Bischoff, Larry Ford and Mary Ann Kendall with the city of Morgan Hill; Reid Fisher and Peter Anderson of Pacific Geotechnical Engineers; and Gwen Ling with Caltrans. At the California Geological Survey I would like to thank Kevin Clahan for collecting and digitizing some of the geotechnical borehole data, Rick Ford for entering all the borehole data into our geotechnical database and for help collecting data, and Anne Rosinksi and Cathy Slater for help with data collection. Special thanks go to Teri McGuire, Barbara Wanish, Bob Moskovitz and Marvin Woods for their GIS operations and database support. Thanks to Keith Knudsen for reviewing this report and for discussions regarding the geologic mapping and interpretation of subsurface deposits, and designation of the zone of required investigation. Thanks to Ralph Loyd and Al Barrows for also reviewing this report.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Morgan Hill 7.5-Minute Quadrangle, Santa Clara County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (Southern California Earthquake Center, 2002). This text is also on the Internet at http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Morgan Hill 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking) complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on CGS's Internet web page: http://www.consrv.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging lifeline infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Morgan Hill Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area.

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared.

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area.

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area.

The data collected for this evaluation were processed into a series of Geographic Information System (GIS) layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide hazard zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide hazard zone or this report. See Section 1, Liquefaction Evaluation Report for the Morgan Hill Quadrangle, for more information on the delineation of liquefaction hazard zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Morgan Hill

Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide hazard zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Morgan Hill 7.5-Minute Quadrangle covers an area of approximately 62 square miles in Santa Clara County, including the southeastern end of Santa Clara Valley. Parts of the cities of Morgan Hill and San Jose lie within the quadrangle. The remainder of the area is unincorporated Santa Clara County land. The major topographic features in the map area are the Santa Clara Valley, which extends diagonally through the map area from southeast to northwest, the Diablo Range, which borders the Santa Clara Valley to the northeast, and the Santa Cruz Mountains, which border the Santa Clara Valley to the southwest.

The Santa Clara Valley is an elongate feature that averages between one and two miles in width in the map area. Most of the valley floor is drained by Coyote Creek, which flows northwestward to San Francisco Bay beyond the map area. A small part of the valley floor in the south part of the map area drains to Llagas Creek, which flows into the Pajaro River south of the map area. Most of the valley in the map area is rural and agricultural. Farm residences are scattered throughout the area and clusters of commercial buildings are located at some of the crossroads. Part of the valley in the southern part of the map area is occupied by the city of Morgan Hill, which includes both residential and commercial development. Major transportation routes include old business Route 101, the modern Interstate Highway 101 freeway, and the Southern Pacific Railway, all of which follow the floor of the Santa Clara Valley.

Steep slopes of the Diablo Range and the Santa Cruz Mountains border the northeastern and southwestern sides of the valley, respectively. In general, development on the mountain slopes is sparse. Anderson Dam impounds Coyote Creek in a canyon at the base of the Diablo Range, adjacent to the east side of the valley floor. The dam impounds a reservoir, Anderson Lake, which fills the lower reaches of several drainages in the lower part of the Diablo Range. The northern margin of Chesbro Reservoir lies in the Santa Cruz Mountains at the southern edge of the map area. Elevations in the map area range from slightly less than 250 feet in Santa Clara Valley at the northwestern edge of the map area to a little over 2,200 feet on Henderson Ridge at the northeastern corner of the map area.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map. Within the Morgan Hill Quadrangle, a Level-2 digital elevation model (DEM) was obtained from the U.S. Geological Survey (1993). This DEM was prepared from topographic contours of the 7.5-Quadrangle quadrangle based on 1953 aerial photography. It has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Three areas along the boundary of the Diablo Range and the Santa Clara Valley have undergone large-scale grading since 1953 for urban development and quarrying. A DEM reflecting these topographic changes was obtained from an airborne interferometric radar platform flown in 1998, with an estimated vertical accuracy of approximately 2 meters (Intermap Corporation, 2003). An interferometric radar DEM is prone to creating false topography where tall buildings, metal structures, or trees are present. The DEM used for the graded areas within the Morgan Hill Quadrangle underwent additional processing to remove these types of artifacts (Wang and others, 2001). Due to the relatively low vegetation and structures present, this type of DEM is appropriate for use in the Morgan Hill Quadrangle. Nevertheless, the final hazard zone map was checked for potential errors resulting from the use of the radar DEM, but no corrections were deemed necessary. The graded areas where the radar DEM was used are shown on Plate 2.1.

A slope gradient map was made from each DEM using a third-order, finite-difference, center-weighted algorithm (Horn, 1981). The slope gradient map derived from the USGS DEM was updated in the graded areas with slope gradients derived from the radar DEM. The manner in which the slope gradient map was used to prepare the zone map is described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The primary sources of 1:24,000-scale bedrock geologic mapping used in this slope stability evaluation were the digital geologic map databases of Wentworth and others (1999), which covers the Diablo Range northeast of Santa Clara Valley, and McLaughlin and others (2001), which covers the Santa Cruz Mountains southwest of the Valley. Knudsen (unpublished) prepared the map of unconsolidated surficial (Quaternary) geologic units for the Morgan Hill Quadrangle at a scale of 1:24,000.

For the purposes of this investigation, CGS geologists merged the surficial and bedrock geologic maps. Contacts between surficial and bedrock units were modified in some areas to resolve differences between the two maps. Geologic reconnaissance was performed to assist in adjusting contacts and to review the lithology and structure of geologic units.

The geologic maps of Wentworth and others (1999) and McLaughlin and others (2001) identify a number of distinct stratigraphic assemblages that are exposed in fault-bounded, bedrock structural blocks in the mountains of Santa Clara County. Five of these bedrock structural blocks extend into the Morgan Hill Quadrangle. The New Almaden Block underlies the northeastern flanks of the Santa Cruz Mountains and portions of the southwestern flank of the Diablo Range. The Silver Creek , Alum Rock , Coyote, and Mount Hamilton blocks are exposed in the Diablo Range on the northeastern side of the Santa Clara Valley.

The concept of individual fault-bounded stratigraphic assemblages in the Bay Area was introduced by Jones and Curtis (1991) and defined further by Graymer and others (1994). Individual stratigraphic assemblages are considered to have originated in separate depositional basins or in different parts of large basins and were later juxtaposed against one another by large displacements on Tertiary strike-slip and dip-slip faults. Each fault-bounded stratigraphic assemblage contrasts with its neighbors in depositional and deformational history. The concept of mapping individual stratigraphic assemblages in discrete bedrock structural blocks has been applied to much of the recent mapping that has been compiled by the U.S. Geological Survey in the Bay Area (for example, Wentworth and others, 1999; McLauglin and others, 2001).

The following sections describe bedrock units in each of the bedrock structural blocks that extend into the Morgan Hill Quadrangle. Unconsolidated Quaternary deposits overlie the bedrock units on the floor of the Santa Clara Valley and in smaller alluvial areas and terraces in the hillside areas. Quaternary deposits in the map area are described in Section 1.

New Almaden Block

The New Almaden Block has a basement consisting of rocks of the Franciscan Complex that are tectonically interleaved with rocks of the Coast Range Ophiolite. These basement rocks are overlain by Miocene marine strata and by deformed Pliocene and Pleistocene fluvial deposits.

McLaughlin and others (2001) mapped units from three lithologic terranes of the Franciscan Complex in the Morgan Hill Quadrangle. These terranes include the melange of the Central Belt Terrane, the Marin Headlands Terrane and the Permanente Terrane.

The melange of the Central Belt Terrane (fm) of Upper Cretaceous age consists of a matrix of penetratively sheared argillite and lithic metasandstone. This matrix encloses various sedimentary, igneous and metamorphic rock blocks and slabs that range from less than a meter to more than a kilometer in diameter. McLaughlin and others (2001) mapped some of the larger blocks in the Morgan Hill Quadrangle, including amphibolite (am), chert (ch) and basaltic volcanic rocks (gs).

Three units of the Marin Headlands Terrane are exposed in the Morgan Hill Quadrangle (McLaughlin and others, 2001). Sandstone (fms) consists of coherent, locally conglomeratic lithic graywacke. Radiolarian chert (fmc) consists of red to green radiolarian chert. Basaltic volcanic rocks (fmv) consist of massive to pillow basalt flows with minor tuff and breccia.

Two units of the Permanente Terrane are exposed in the Morgan Hill Quadrangle (McLaughlin and others, 2001). Foraminiferal limestone (fpl) consists of pelagic gray, gray-green, black and pink foraminiferal limestone and minor black to gray nodular to lenticular radiolarian chert. Volcanic rocks (fpv) include pillow basalt flows, flow breccias and andesitic tuff.

Serpentinized ultramafic rocks (Jos) are complexly interleaved with the melange in the Franciscan Complex. These rocks are intensively sheared and may have been derived from ophiolite of the Sierra Azul block, which structurally underlies the New Almaden block (McLaughlin and others, 2001).

Miocene marine rocks of the New Almaden Block do not extend into the Morgan Hill Quadrangle but are exposed east of the map area. A small exposure of the Plio-Pleistocene Santa Clara Formation (QTsc) is exposed in the New Almaden Block on the northeastern margin of the Santa Clara Valley. The Santa Clara Formation consists of fluvial boulder to pebble conglomerate, sandstone, siltstone and minor lacustrine mudstone (McLaughlin and others, 2001).

Silver Creek Block

The Silver Creek Block is exposed on the east side of the southern Santa Clara Valley and is characterized by Tertiary stratigraphy that is distinct from adjoining bedrock structural blocks. The basement rocks of the Silver Creek Block consist of Franciscan melange (fm) and serpentinite of the Coast Range Ophiolite (Jos) that also are exposed in the New Almaden Block, as described above. The Mesozoic basement rocks of the Silver Creek Block structurally underlie and overlie Cretaceous and Tertiary strata. All of the rocks are, in turn, unconformably overlain by the Packwood Gravels (QTp) (Wentworth and others, 1999).

Cretaceous strata, mica-rich Miocene sandstone and Miocene andesite and basalt are distinctive units of the Silver Creek Block but are not exposed in the Morgan Hill Quadrangle. Overlying these units are the upper Miocene to Pliocene Silver Creek Gravels (Tsg), which are widely exposed in the hills on the east side of the Santa Clara Valley, west and northwest of Anderson Reservoir. The Silver Creek Gravels consist of interbedded conglomerate, sandstone, siltstone, tuffaceous sediment, tuff and basalt. The Silver Creek Gravels are distinguished from similar gravels, such as the Packwood Gravels and the Santa Clara Formation, by the presence of interbedded white tuff layers and other volcanic rocks, beds of nonmarine red and green mudstone, by the relatively well-consolidated nature of the conglomerate beds, and by the characteristic clast composition. About 75 percent of the clasts are Franciscan Complex rocks with the remaining 25 percent consisting of volcanic rocks, Claremont siliceous shale and chert, and other Cenozoic rocks. Pliocene basalt and andesite (Tba) is exposed in contact with the Silver Creek Gravels near Anderson Dam (Wentworth and others, 1999).

The Plio-Pleistocene Packwood Gravels (QTp) consist of silty and fine sandy pebble conglomerate, fine silty sandstone, pebbly to fine sandy siltstone, and minor olive-green claystone beds. Numerous nonmarine red mudstone beds also are present. Most of the clasts are derived from rocks of the Great Valley Sequence rather than the Franciscan Complex. This unit overlies the Silver Creek Gravels along an angular unconformity (Wentworth and others, 1999).

Silica carbonate rock (scm) consists of siliceous and calcareous deposits resulting from hydrothermal alteration of serpentinite. This rock is exposed in association with Coast Range Ophiolite (Jos) in a few small areas on the west side of Anderson Lake and north of Metcalf Canyon (Wentworth and others, 1999).

Alum Rock Block

The Alum Rock Block consists of Jurassic through Quaternary strata that were deposited on the Jurassic Coast Range Ophiolite and associated intermediate and silicic volcanic rocks. Only a small part of the Alum Rock Block extends into the Morgan Hill Quadrangle, along the northern border of the map area.

In the map area, the Jurassic Coast Range Ophiolite consists of serpentinized ultramafic rocks (Jos). Associated with the Coast Range Ophiolite are basalt, keratophere and quartz keratophere (Jbk), which are considered to be the remnants of island arc volcanic deposits (Wentworth and others, 1999). Also associated with the Coast Range Ophiolite are intrusive diabase, diorite and gabbro (Jic), which are considered to be remnants of the lower oceanic crust (Wentworth and others, 1999). The Knoxville Formation of Late Jurassic and Early Cretaceous age is the lowermost unit of the Great Valley Sequence deposited on the Coast Range Ophiolite. It consists of dark, greenish-gray shale with thin sandstone interbeds.

The Alum Rock Block includes a number of other Cretaceous and Tertiary units; however, these do not extend into the map area.

Coyote Block

The Coyote Block consists of Coast Range Ophiolite rocks overlain by Cretaceous strata of the Great Valley Sequence and Tertiary strata. The strata dip steeply to the east and are cut by numerous transpressive faults (Wentworth and others, 1999). The Coyote Block extends into the northeastern part of the Morgan Hill Quadrangle.

The oldest rocks in the map area consist of Cretaceous sandstone, mudstone and conglomerate (Kcusm) within the Great Valley Sequence. Sandstone is fine to coarse grained with interbedded biotite-rich siltstone and dark gray mudstone. Conglomerate layers contain boulder to pebble clasts of silicic to intermediate volcanic rocks, limestone, metavolcanics and rip-up clasts of mica-rich sandstone (Wentworth and others, 1999).

The oldest Tertiary unit of the Coyote Block in the map area is an unnamed Eocene brown-weathering mudstone (Tbmw) that locally contains fine-grained sandstone and, in one outcrop, coarse glauconitic sandstone with foraminifera of middle Eocene age. The upper to middle Miocene Claremont Formation (Tcc) is also present in the map area. This unit consists of chert and siliceous shale that locally contains lenses of dolomite and some thin beds of quartz sandstone and siltstone. The upper Miocene Briones Formation (Tbr) unconformably overlies the Claremont Formation. The Briones Formation is predominantly sandstone with conglomeratic sandstone, shell-hash conglomerate containing interlocking mollusk and barnacle shells, and siltstone (Wentworth and others, 1999).

Mount Hamilton Block

The Mount Hamilton Block forms the core of the Diablo Range and primarily consists of Franciscan rocks with scattered small bodies of serpentinite derived from the Coast Range Ophiolite (Wentworth and others, 1999). The Franciscan rocks are overlain unconformably by Miocene marine sedimentary rocks that are exposed in limited areas at the margins of the block.

The Mount Hamilton Block is exposed in a very small area that lies in the northeast corner of the map area. In the map area, the block contains Franciscan melange (fm) and bodies of chert (ch) as described above in the section on the New Almaden Block. The block also contains Franciscan metagraywacke of the Cretaceous (?) and Jurassic Yolla Bolly Terrane, which is structurally interleaved with Franciscan melange (Wentworth and others, 1999). Metagraywacke of the Yolla Bolly terrane contains metamorphic minerals of the blueschist facies.

Structural Geology

The bedrock units in the Morgan Hill Quadrangle have undergone a complex structural history and are strongly deformed by faults and folds of various ages. As discussed in the previous section, the bedrock units in the Morgan Hill Quadrangle are separated into a number of separate bedrock structural blocks, each of which has undergone a separate depositional and deformational history (Wentworth and others, 1999; McLaughlin and others, 2001).

The oldest fault is the Coast Range Fault, which was formed during Jurassic subduction of Franciscan rocks below the Coast Range Ophiolite. Originally, the sense of displacement across the Coast Range Fault was reverse, but subsequent attenuation displacements have taken place associated with Cenozoic uplift and unroofing of Franciscan basement rocks. Discontinuous segments of the Coast Range Fault occur in the map area where Coast Range Ophiolite is juxtaposed against Franciscan rocks.

Numerous northwest-trending transpressive and strike-slip faults extend through the area. The youngest of these is the Calaveras Fault, which is considered to be Holocene active based on active seismicity, offset Holocene deposits observed in exploratory trenches at Lydell Creek, north of the map area, and prominent linear geomorphic features observed at many places along the fault. The Calaveras Fault extends along the east side of Anderson Lake and continues into adjacent quadrangles north of the Morgan Hill map.

Numerous other transpressive faults displace Cenozoic rocks and, in some cases, Pleistocene gravels in or near the map area.

Deformational features differ in each of the bedrock structural blocks in the map area. The New Almaden Block has been warped by northeast-southwest compression into a broad, weakly defined, antiform and synform structure. The axis of the antiform structure, the Uvas antiform, is in the Santa Teresa Hills Quadrangle, west of the Morgan Hill Quadrangle (McLaughlin and others, 2001). The Silver Creek Block contains Mesozoic basement rocks that have been thrust over tightly folded Cretaceous and Tertiary strata along the Silver Creek Thrust (Wentworth and others, 1999). The Alum Rock Block contains a steeply dipping sequence of strata that are repeated by displacements along Tertiary and Quaternary transpressive faults. Some of these faults displace Pleistocene gravels north of the study area. The Coyote Block also consists of steeply dipping strata that are cut by reverse and transpressive faults. The Mount Hamilton Block is a massive uplifted block of complexly interleaved Franciscan rocks.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Morgan Hill Quadrangle has been prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Landslides were mapped at a scale of 1:24,000. For each landslide included on the map, a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis as described later in this report. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included on Plate 2.1.

The most prominent aspect of the Morgan Hill Quadrangle landslide inventory is a preponderance of large, deep-seated landslides in areas underlain by the Silver Creek Gravels. Much of the hilly terrain bordering the western shoreline of Anderson Lake and extending for several miles northwest of the lake is underlain by very large landslide masses that have developed in the Silver Creek Gravels. On the eastern side of the lake, a number of smaller, relatively shallow landslides have developed in the Packwood Gravels. A few relatively large landslides have developed in serpentinite of the Coast Range Ophiolite and in Franciscan mélange. However, these units generally form relatively stable slopes in the map area compared to some other areas in the region where abundant landslides have formed in these units. At the southwestern corner of the map area, two large debris flow deposits are present. The toe of the larger debris flow deposit is directly adjacent to the channel of Llagas Creek, and it may have blocked the channel when initially deposited.

Because it is not within the scope of the Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether or not surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Morgan Hill Quadrangle geologic map were obtained from the city of Morgan Hill, Santa Clara County Planning Department, and Pacific Geotechnical Engineering, as detailed in the Appendix. The locations of rock and soil samples taken for shear testing within the Morgan Hill Quadrangle are shown on Plate 2.1. Shear tests from adjoining portions of San Jose East, Santa Teresa Hills, Mount Sizer, Mount Madonna and Gilroy quadrangles were used to augment data for several geologic units for which little or no shear-test information is available within the Morgan Hill Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength groups are summarized in Table 2.1. For each geologic strength group (Table 2.2) in the map area, the average shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Geologic units for which no shear tests are available are grouped based on lithologic similarity and surface expression. Because of similar field characteristics (Graymer, 1995), QTsc is grouped with QTp even though the few tests would otherwise suggest a higher strength. All Holocene units, including Holocene/late Pleistocene units (Qa and Qf) are combined into Qh because of their similar ages, lithologies and densities. Likewise, all Pleistocene units are combined into Qp/Qo.

The median value (11^{o}) for Group 4 is used for the stability analysis because the sample population is too small to justify using the mean (13^{o}).

Existing Landslides

As discussed later in this report, the criteria for zoning earthquake-induced landslide hazards state that all existing landslides mapped as definite or probable are included in the hazard zone. Therefore, shear-strength parameters for existing landslides are not necessary for preparing the zone map. However, in the interest of completeness for the geologic material strength map, to provide relevant shear-strength data to project plan reviewers, and to allow for future revisions of our zoning procedures, we have compiled shear-strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide hazard zone map, the slip surfaces of all landslides within the quadrangle are assumed to have the same strength parameters. We collect and use primarily "residual" strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. For the Morgan Hill Quadrangle, six direct shear tests of landslide slip surface materials were obtained, and the results are summarized in Table 2.1.

SHEAR-STRENGTH STATISTICS FOR THE MORGAN HILL 7.5-QUADRANGLE QUADRANGLE

	Formation Name (1)	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (2) (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	fmv	6	32.0 / 32	32.8 / 33	530 / 600	am	33
	fpv	3	34.7 / 37			Jbk	
	KJk	5	32.6 / 41			scm	
						Tbr	
GROUP 2	af (3)	10	25.4 / 29	27.0 / 26	764 / 550	alf (3)	27
	ch	1	29.0			fmc	
	Jos	33	25.7 / 24			fms	
	Qp/Qo	50	26.0 / 26			fpl fys	
	QTp	17	31.2 / 28			gs Jic	
	QTsc	2	37.0			Kcusm	
	Tsg	10	28.1 / 26			Tbmw	
GROUP 3	fm	26	22.9 / 21.5	23.5 / 22.6	674 / 550	ac (3)	23
	Qh	53	23.8 / 23			gq (3)	
	Tba	1	18.0			Tcc	
GROUP 4	Qls	6	12.9 / 11	12.9 / 11	872 / 1175	- - -	11

(1) Formation name abbreviations for strength groups from McLaughlin and others (2001); Knudsen (unpublished). The Quaternary is grouped as Qh for Holocene units and Qp/Qo for Pleistocene/Older units.
(2) Cohesion
(3) ac - artificial channel, af - artificial fill, alf - artificial levee fill, gq - gravel quarry or percolation pond.

Table 2.1. Summary of Shear-Strength Statistics for the Morgan Hill Quadrangle.

SHEAR-STRENGTH GROUPS FOR THE MORGAN HILL 7.5-QUADRANGLE QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
am	af alf ch	ac	Qls
fmv	fmc fms	fm	
fpv	fpl fys gs	gq	
Jbk	Jic Jos	Qh	
KJk	Kcusm	Tba	
scm	Qp/Qo	Tcc	
Tbr	QTp QTsc		
	Tbmw Tsg		

Table 2.2. Summary of Shear-Strength Groups for the Morgan Hill Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide hazard zones, the Newmark method necessitates selecting a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Morgan Hill Quadrangle, selection of a strong motion record is based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). These parameters are estimates from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.7 - 7.9
Modal Distance:	9.0 - 21.7 km
PGA:	0.55 - 0.67 g

The strong-motion record selected for the slope stability analysis is Southern California Edison's Lucerne record from the 1992 Landers earthquake, which had a moment magnitude (M_W) of 7.3. The east-west component of this record had a PGA of 0.73 g and a source-to-recording-site distance of 1.1 km. Although the distance and PGA from the Lucerne record fall outside the range of the probabilistic parameters, this record is considered to be sufficiently conservative to be used in the stability analyses for the

Morgan Hill Quadrangle. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relation between landslide displacement and yield acceleration, defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relation was determined by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of accelerations (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm are used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.14, 0.18 and 0.24 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Morgan Hill Quadrangle.

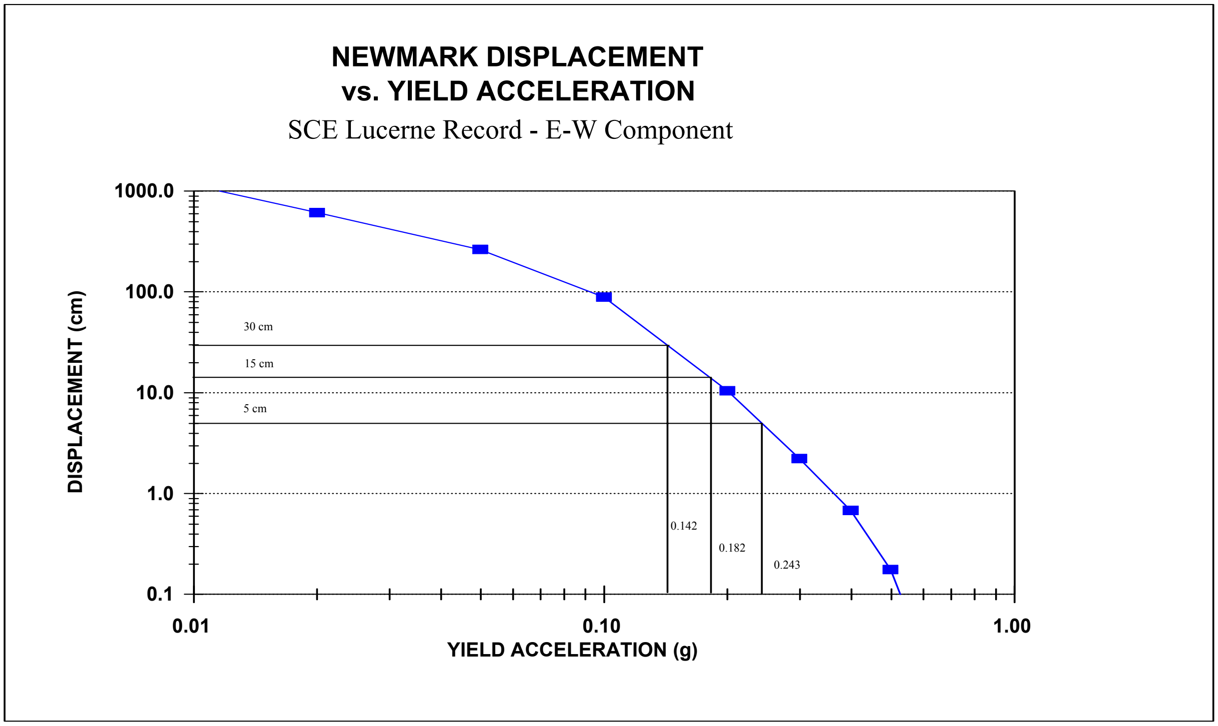

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record from the 1992 Landers Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration ($\mathbf{a_y}$) from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic strength group for a range of slope gradients. Based on the relation between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.14 g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned.

2. If the calculated yield acceleration fell between 0.14 g and 0.18 g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned.

3. If the calculated yield acceleration fell between 0.18 g and 0.24 g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned.

4. If the calculated yield acceleration was greater than 0.24 g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned.

Table 2.3 summarizes the results of the stability analysis. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material strength map and the slope map according to this table.

HAZARD POTENTIAL MATRIX FOR THE MORGAN HILL 7.5-QUADRANGLE QUADRANGLE					
Geologic Strength Group	**Average Phi**	**HAZARD POTENTIAL (Percent Slope)**			
		Very Low	**Low**	**Moderate**	**High**
1	**33**	**0 to 39%**	**39 to 45%**	**45 to 49%**	**> 49%**
2	**27**	**0 to 26%**	**26 to 32%**	**32 to 36%**	**> 36%**
3	**23**	**0 to 18%**	**18 to 23%**	**23 to 28%**	**>28%**
4	**11**	**0%**	**0%**	**0 to 5%**	**> 5%**

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Morgan Hill Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide hazard zones have been delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, **all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone**.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength groups and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

- Geologic Strength Group 4 is included for all slope gradients.
- Geologic Strength Group 3 is included for all slopes steeper than 18 percent.
- Geologic Strength Group 2 is included for all slopes steeper than 26 percent.
- Geologic Strength Group 1 is included for all slopes steeper than 39 percent.

Approximately 35 percent of Morgan Hill Quadrangle is within the earthquake-induced landslide hazard zone. The zones are all within the hilly and mountainous areas.

ACKNOWLEDGMENTS

The Community Development Department for the city of Morgan Hill, Peter Anderson and the staff of Pacific Geotechnical Engineering, and James Baker with the county of Santa Clara assisted us in retrieving necessary geotechnical data and granted us full access to their files. At CGS, Tim McCrink delineated the graded areas and gave helpful advice on evaluating the shear-strengths. Sam Altashi and Ellen Sander entered the sample and testing information into our database. Barbara Wanish, Terilee McGuire, Lee Wallinder, and Bob Moscovitz provided invaluable GIS and database support. Barbara Wanish and Diane Vaughan prepared the final landslide hazard zone maps and graphic displays.

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WAC Corporation, Inc., dated 4-14-99, Flight Number WAC-C-99CA, Photo Numbers 7-135 through 7-142; 7-203 through 7-210; 8-14 through 8-21; 8-97 through 8-100.

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APPENDIX
SOURCE OF SHEAR-STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Morgan Hill	**22**
Santa Clara County	**2**
Pacific Geotechnical Engineering	**6**
Total Number of Shear Tests	**30**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Morgan Hill 7.5-Minute Quadrangle, Santa Clara County, California

By

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California Geological Survey
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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/SHMPsp117.asp

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.consrv.ca.gov/CGS/index.htm

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

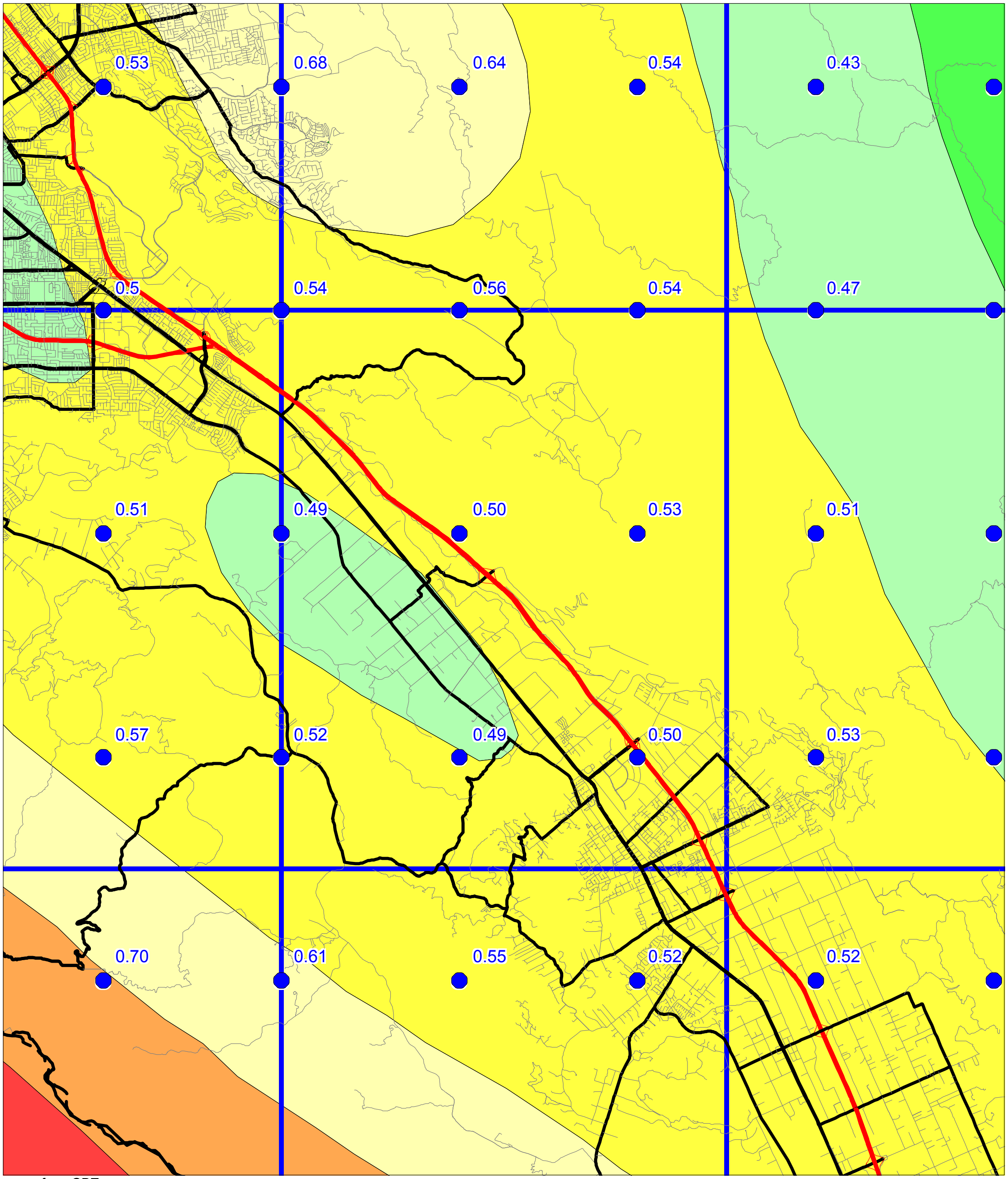
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight

MORGAN HILL 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

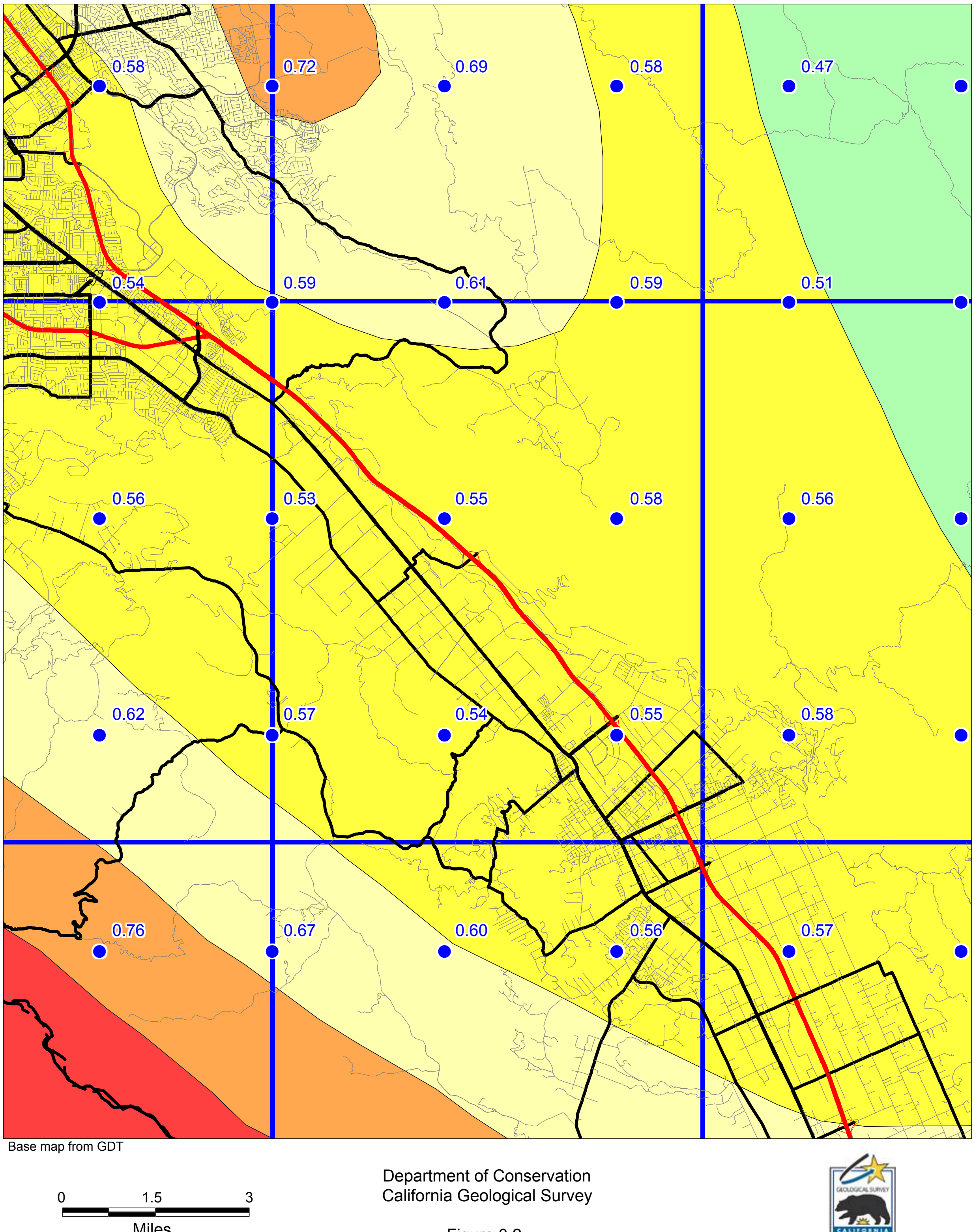
Figure 3.1

MORGAN HILL 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



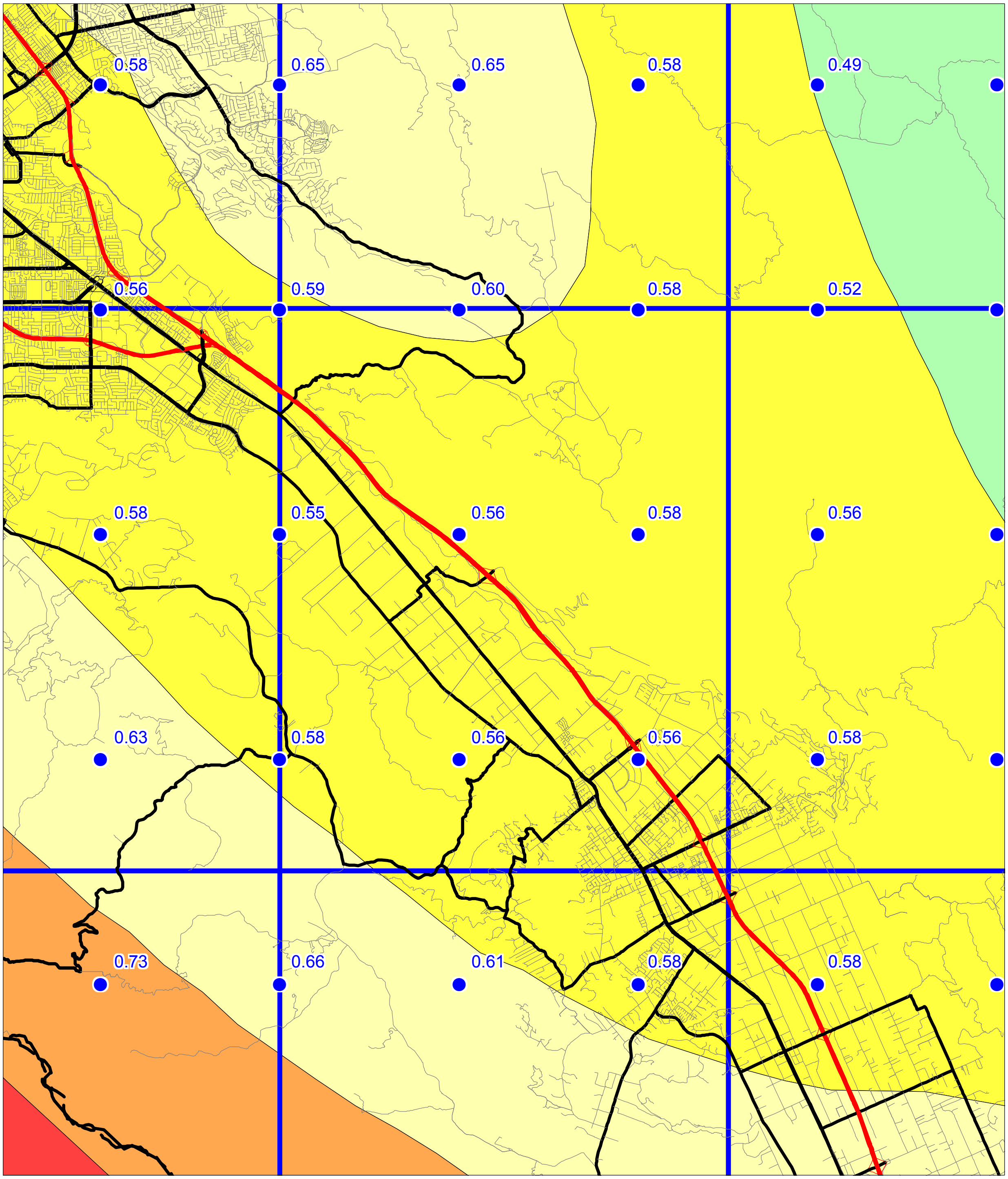
Department of Conservation
California Geological Survey

Figure 3.2

MORGAN HILL 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.3

adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the "simplified Seed-Idriss method" of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a "magnitude-weighted" ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

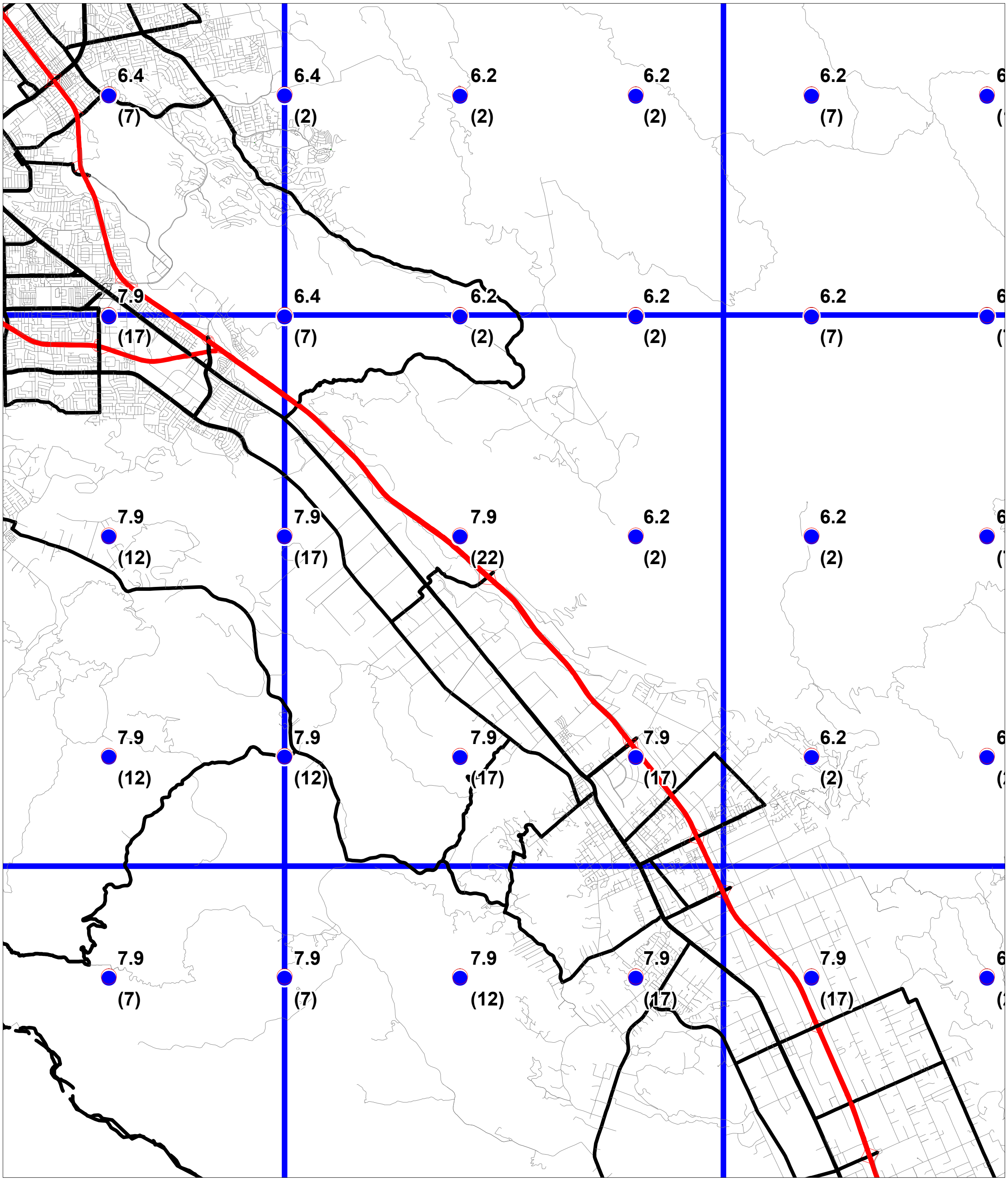
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss' weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

MORGAN HILL 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map from GDT

0 1.5 3
Miles

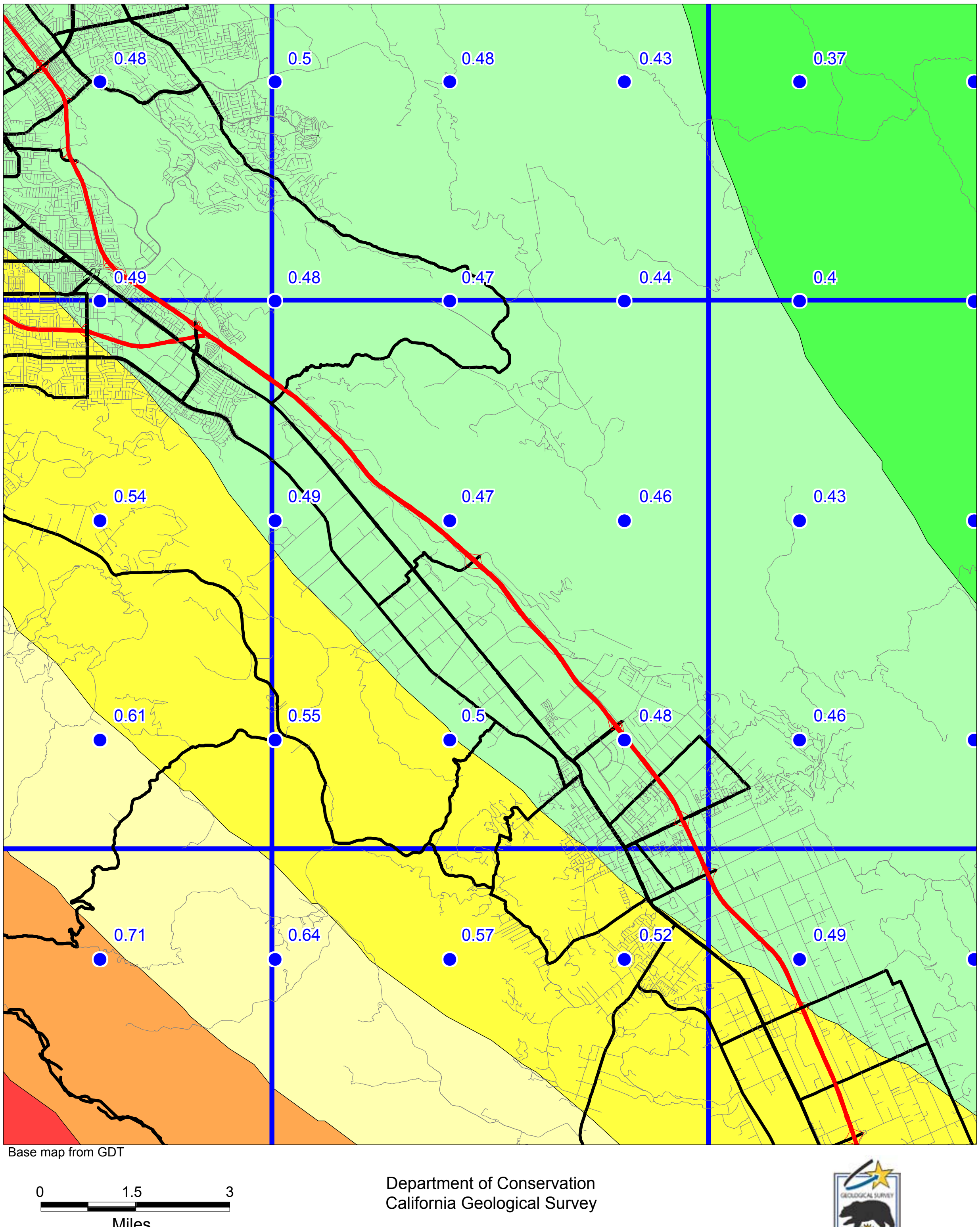
Department of Conservation
California Geological Survey
Figure 3.4

MORGAN HILL 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

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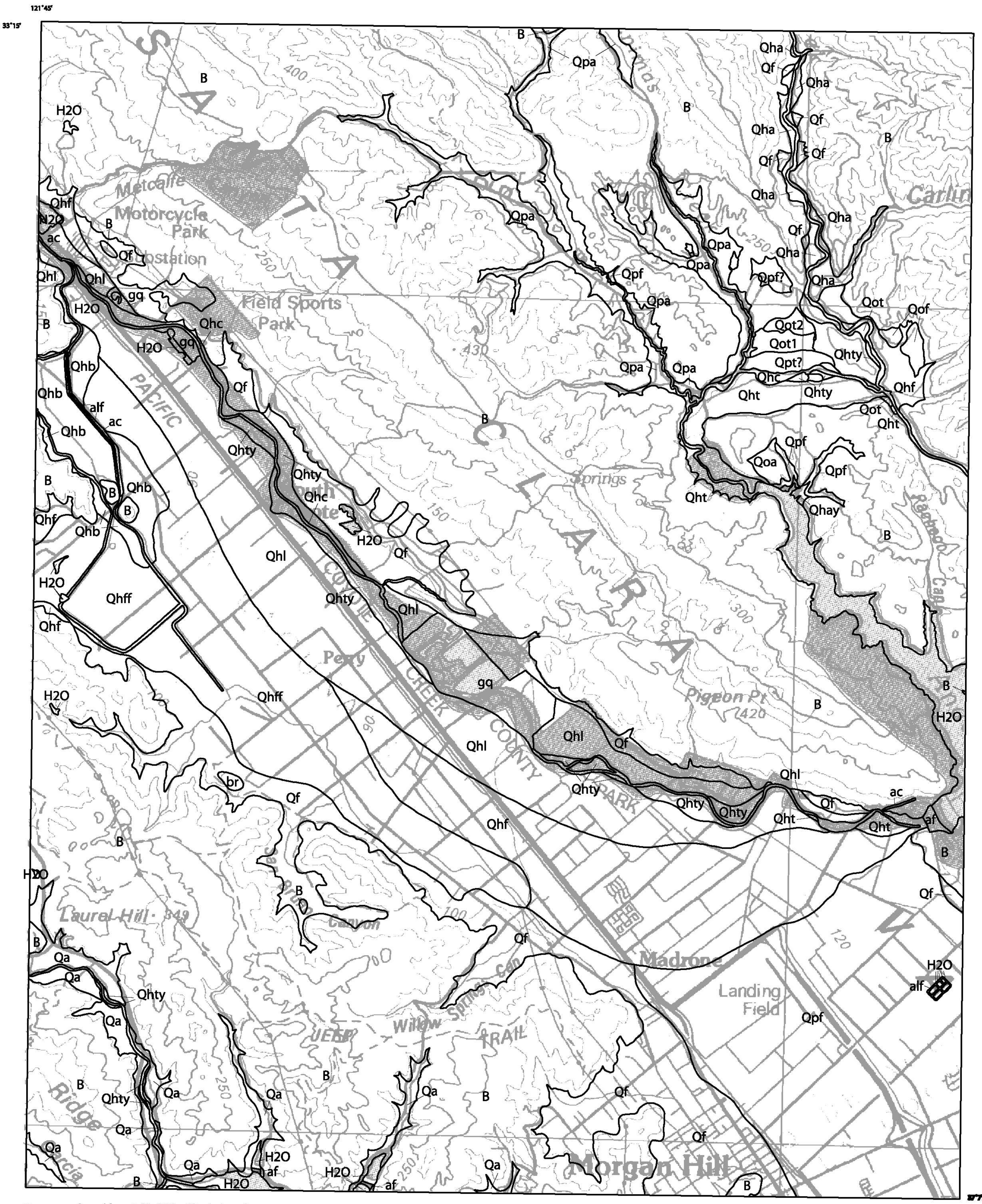
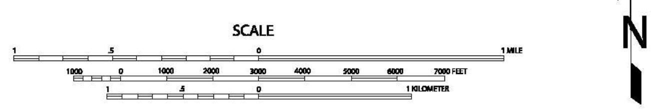


Base map enlarged from U.S.G.S. 30 x 60-minute series

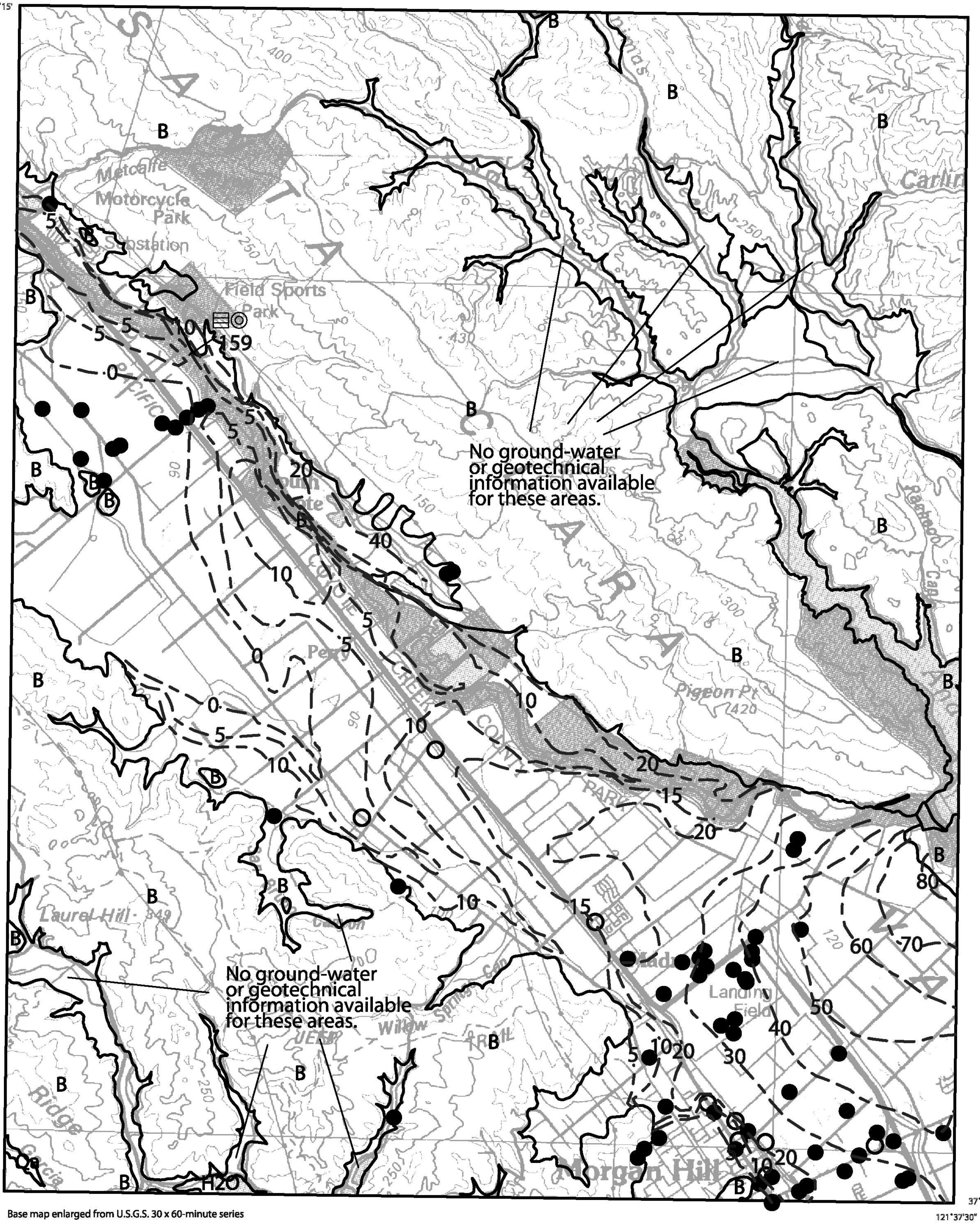
MORGAN HILL QUADRANGLE



B = Pre-Quaternary bedrock.

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary Geologic Map of the Morgan Hill 7.5-minute Quadrangle (unpublished mapping by K.L. Knudsen and R.C. Witter)



Base map enlarged from U.S.G.S. 30 x 60-minute series

MORGAN HILL QUADRANGLE

SCALE

N

Historical Ground Failures (modified from Knudsen and others, 2000)

Sand boils

Ground cracks

B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Geotechnical borings used in liquefaction evaluation

Santa Clara Valley Water District ground-water level measurements

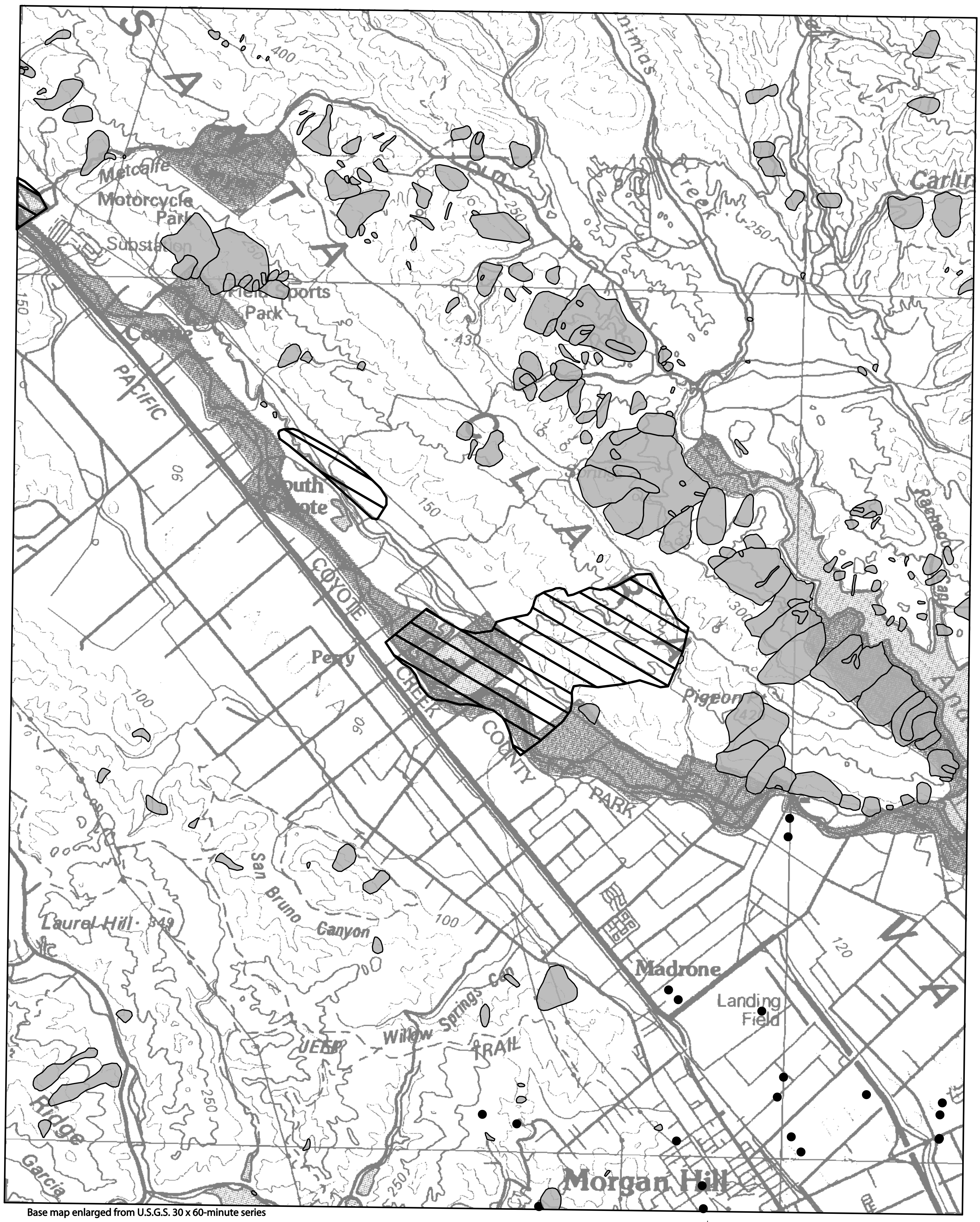
50 Depth to ground water, in feet

Plate 1.2 Depth to historically high ground water, and locations of boreholes used in this study, Morgan Hill 7.5-minute Quadrangle, California. Ground-water contours based on Clark (1916).

CALIFORNIA GEOLOGICAL SURVEY
MICHAEL S. REICHLE, ACTING STATE GEOLOGIST

STATE OF CALIFORNIA- ARNOLD SCHARZENEGGER, GOVERNOR
THE RESOURCES AGENCY-MICHAEL CHRISMAN SECRETARY
DEPARTMENT OF CONSERVATION-DARRYL W. YOUNG, DIRECTOR

121°07'30"
37°07'30"



Base map enlarged from U.S.G.S. 30 x 60-minute series

37°07'30"
121°07'30"

MORGAN HILL QUADRANGLE

SCALE

0 .5 0 1 MILE
1000 0 2000 4000 6000 FEET
1 .5 0 1 KILOMETER

N

● Shear test sample location

Landslide

Area of significant grading

Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Morgan Hill 7.5-Minute Quadrangle, California.